High Contrast Imaging Testbed
&
2-m Class Mission Concept

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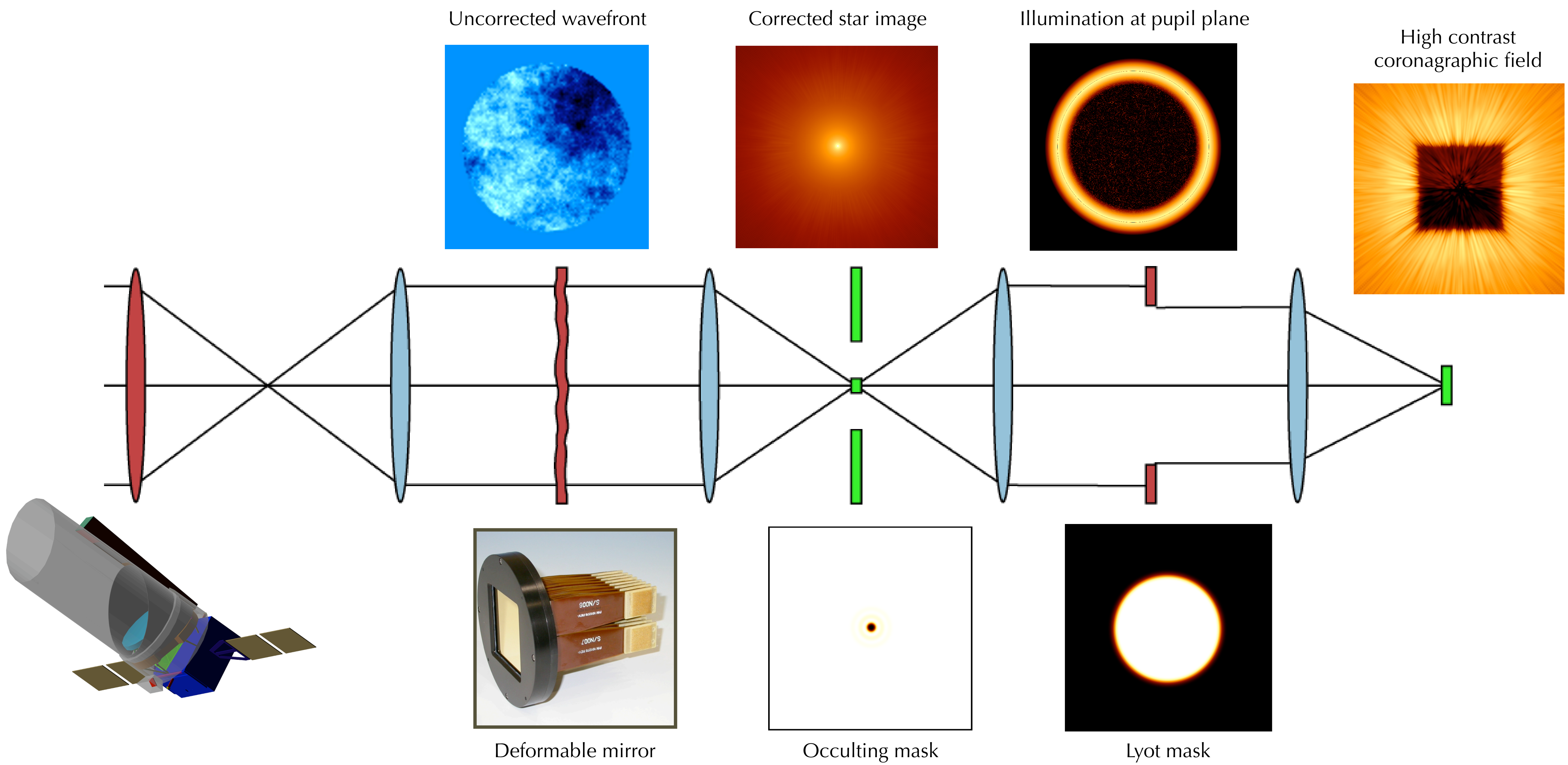
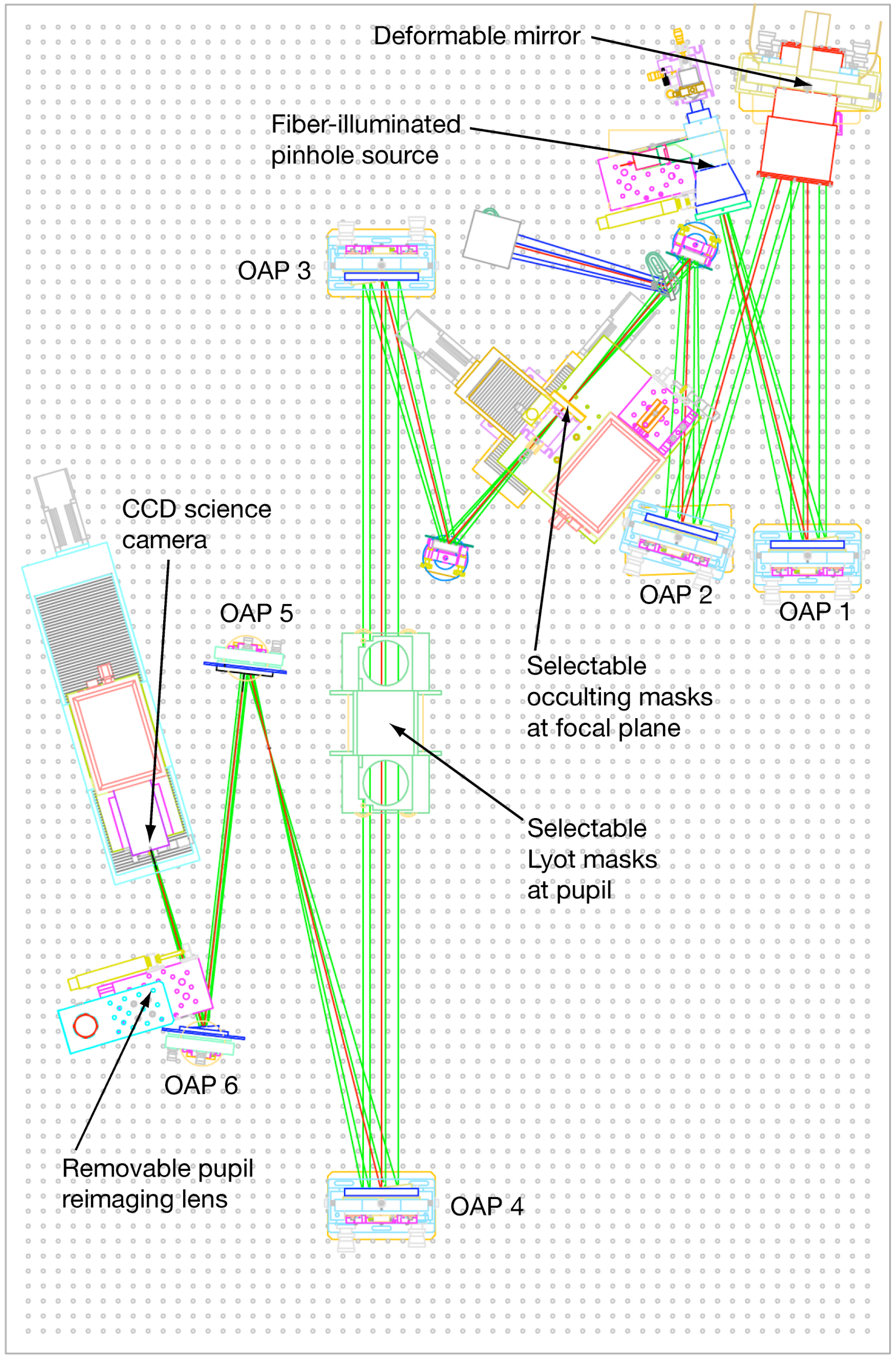
Objectives of the High Contrast Imaging Testbed

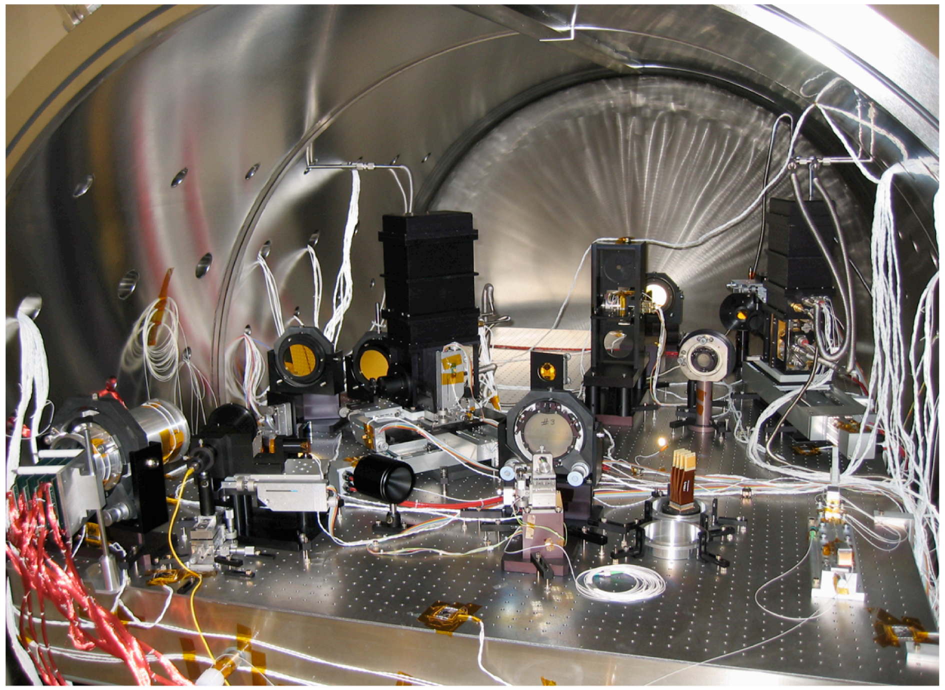
- Our objective is to establish and maintain a laboratory facility where we can:
- Advance the state-of-the-art and TRL levels for space coronagraph hardware, techniques, and algorithms;
- Provide proof-of-concept demonstrations of coronagraph techniques, including TPF-C milestones; and
- Support collaborations across the exoplanet community in pursuit of the optimal space coronagraph architecture.

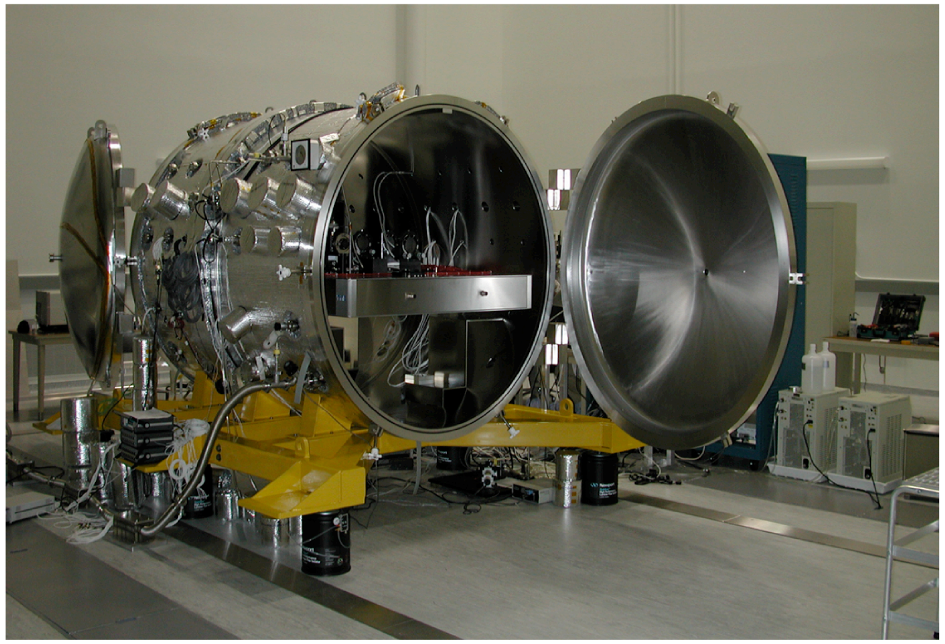
The HCIT captures the essential elements of a space coronagraph with minimal optics



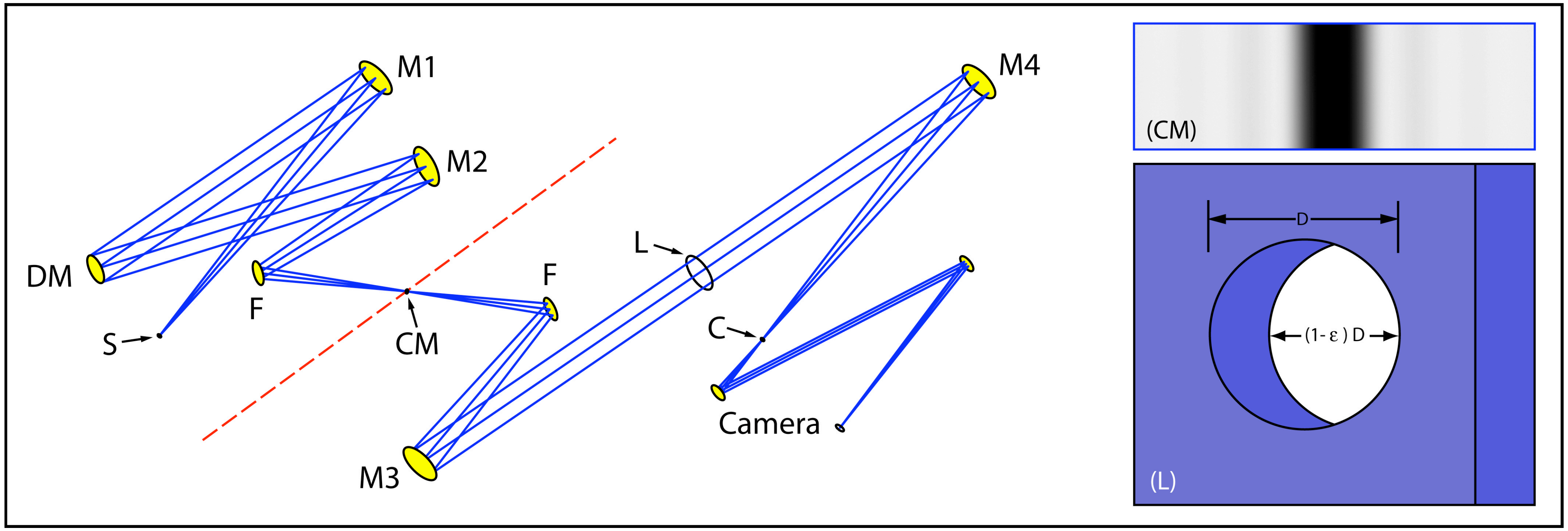
High Contrast Imaging Testbed at JPL





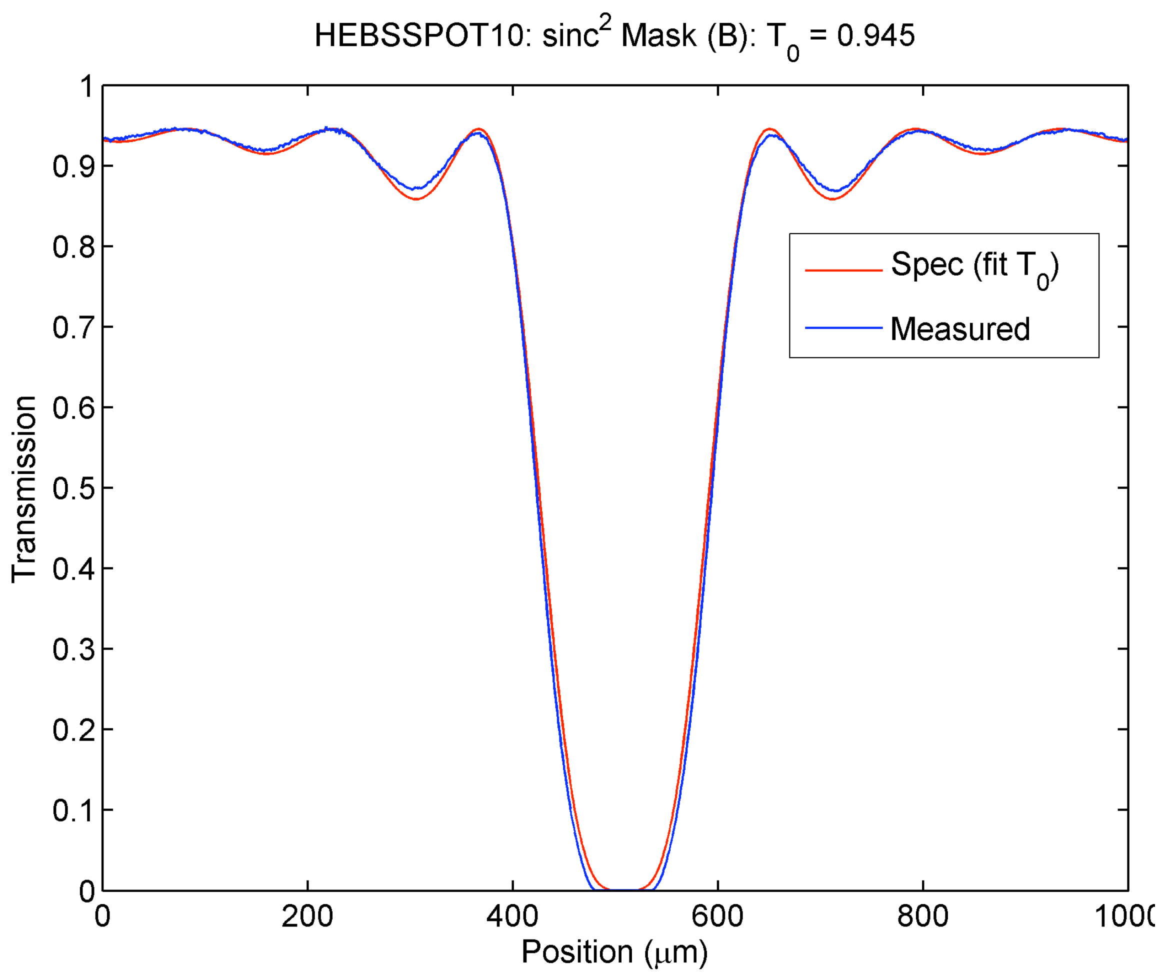


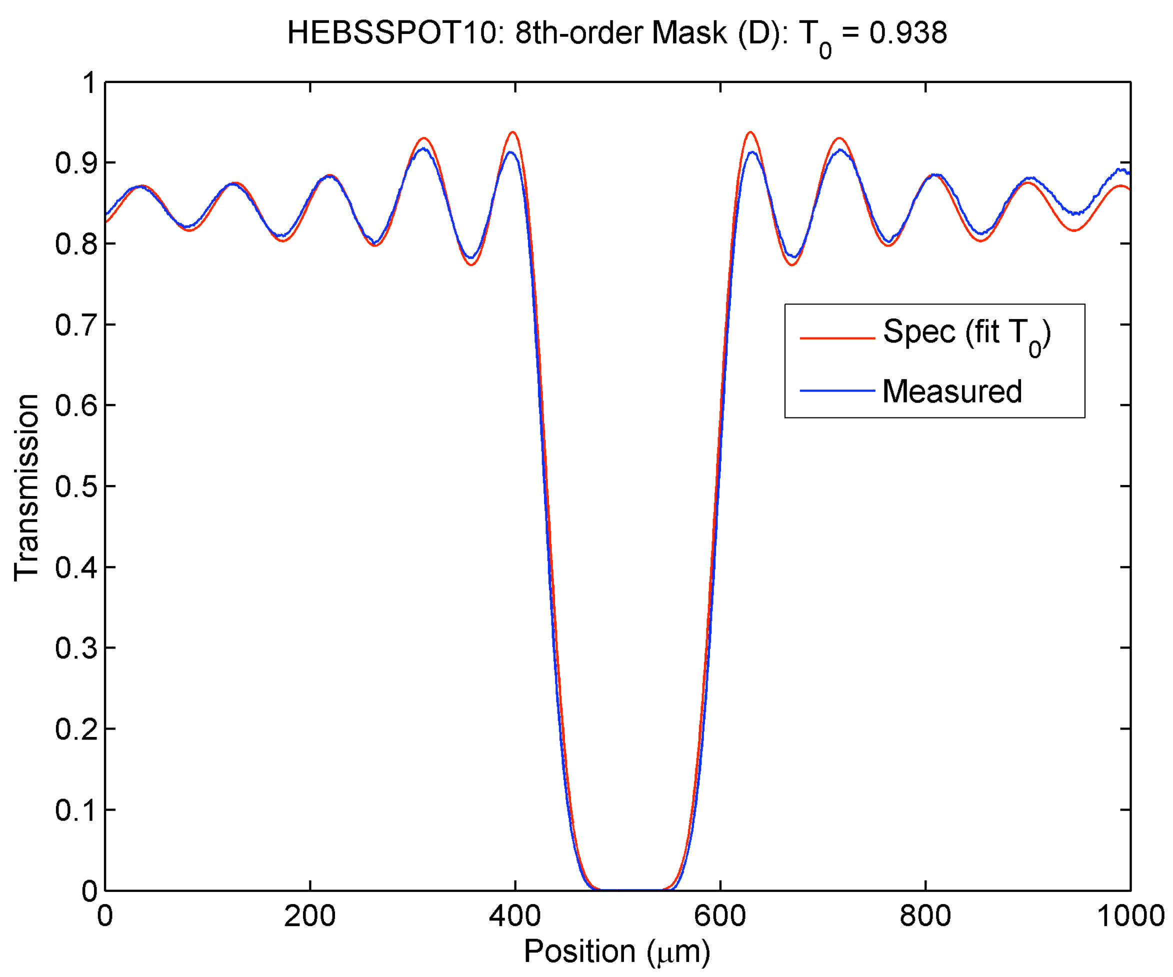
HCIT coronagraph layout



Elements of the HCIT Lyot coronagraph: the light source (S) is a 5 micron pinhole illuminated by light relayed from a fiber; four identical off-axis paraboloidal mirrors (M1, 2, 3, 4); two flat fold mirrors (F), the band-limited focal plane mask (CM); the Lyot mask (L); the high-contrast coronagraph field appears at (C); and the CCD camera with a pair of OAP mirrors for 3x magnification.

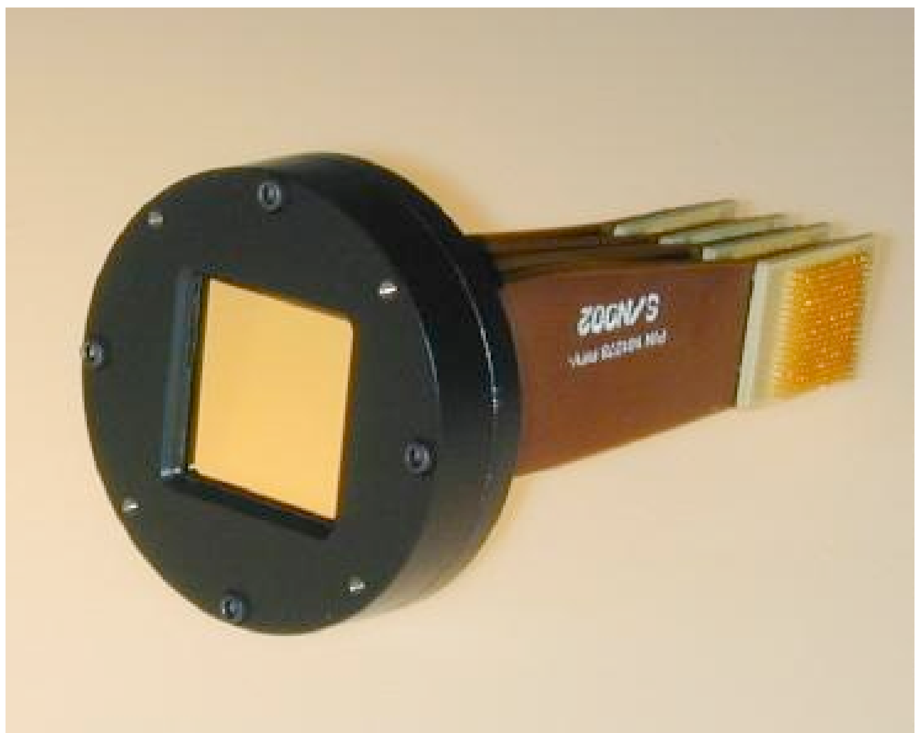
Measured Lyot occulter profiles



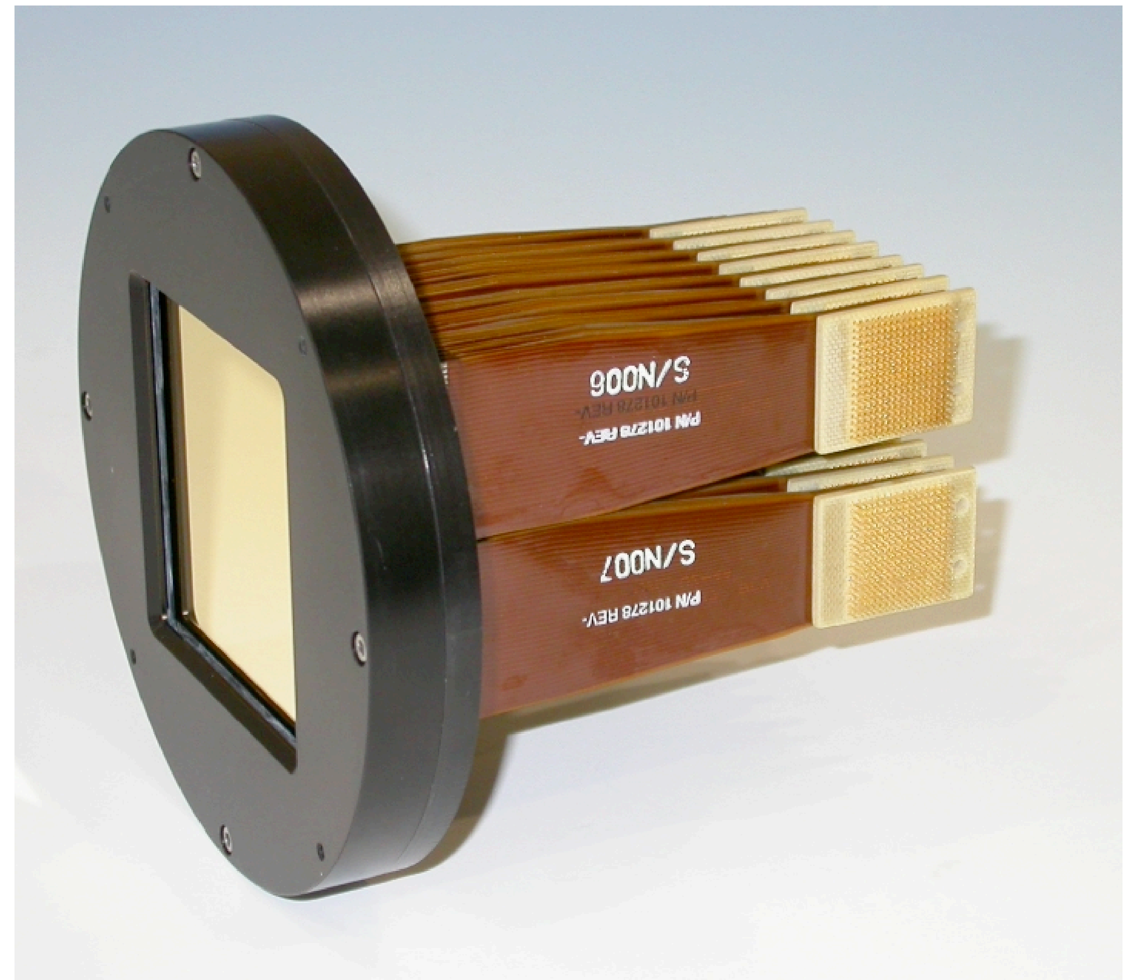


Linear 4th-order (left) and 8th-order (right) masks written in HEBS glass (Canyon Materials) at JPL's Microdevices Laboratory. Transmittance profiles have been measured under a microscope and compared with their respective analytic prescriptions.

Active wavefront correction with Deformable Mirrors (DM)

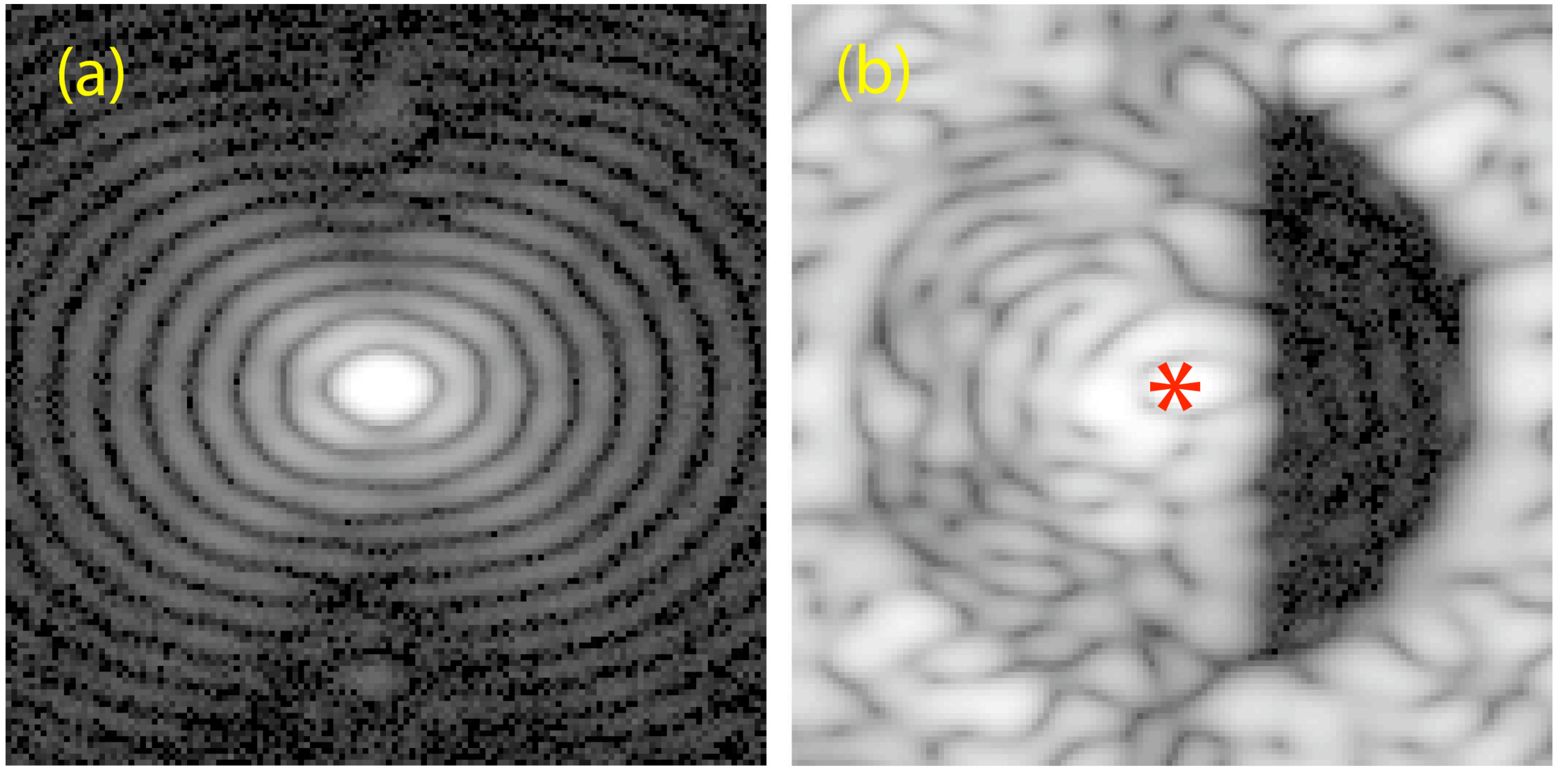


Fifth in a series of Gen2 32x32 mm DMs delivered to JPL by Xinetics. DM surface is polished to $\lambda/100$ rms. Surface figure (open loop) is stable to 0.01 nm rms.



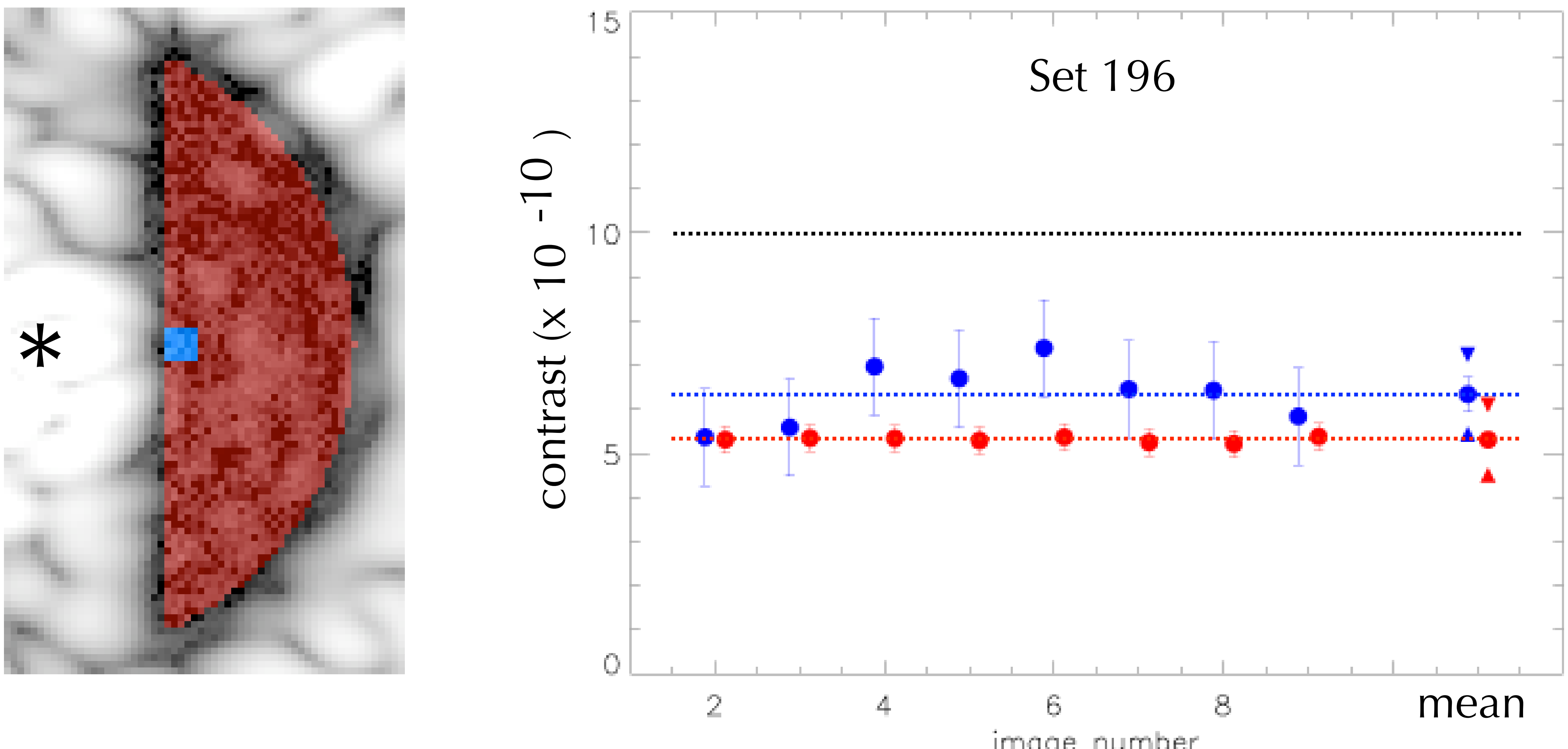
Gen2 64x64 mm DM delivered to JPL. The same 32x32 actuator technology is repeated four times, bonded together, with a single facesheet.

HCIT coronagraph PSF and dark field



HCIT coronagraph PSFs: (a) the star with focal plane mask removed and Lyot mask in place; and (b) the dark half-field with DM voltages set initially by speckle nulling.

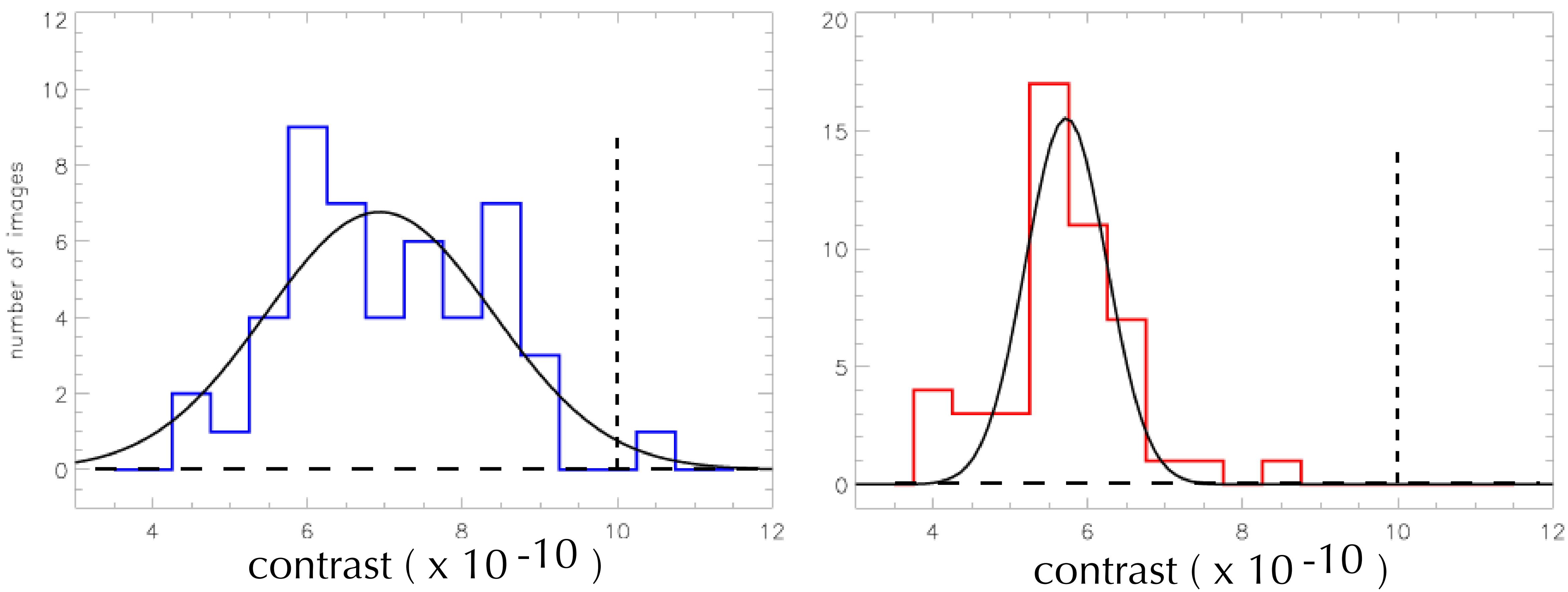
Speckle nulling demonstrations with the HCIT



Contrast obtained in a sequence of images over a representative one-hour period. At left is the high contrast field: the inner and outer target areas are highlighted in blue and red respectively; an asterisk marks the location of the occulted “star”. Plotted at right are contrast values averaged over the inner and outer areas (again in blue and red respectively) for each image in the sequence. One-σ error bars indicate the measurement noise estimated from pairwise data.

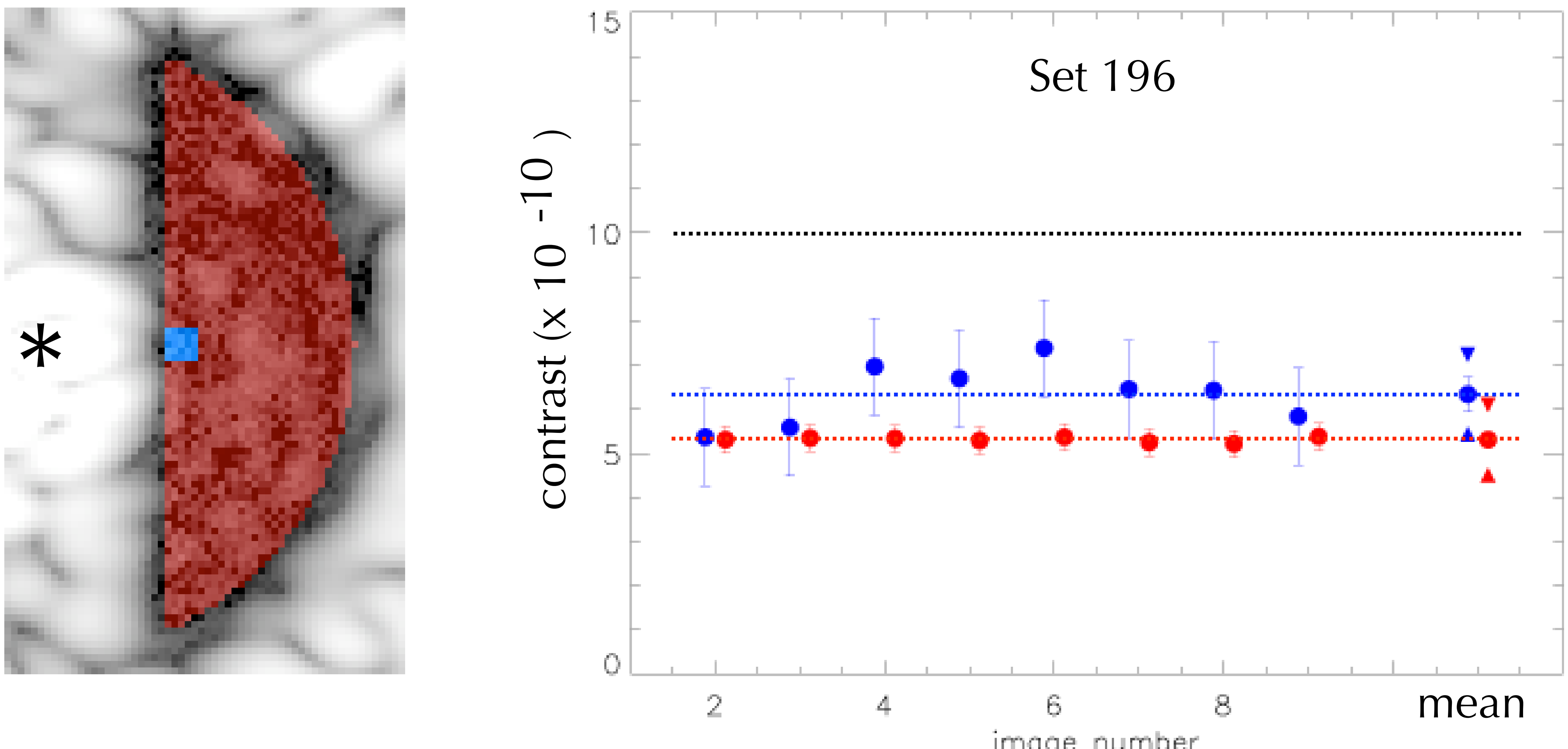
Repeatability in a sequence of data sets

Inner 4-5 λ/D Outer 4-10 λ/D



Summary of contrast measured during six different hour-long data sets (distributed over one week) in the inner and outer high contrast fields (again in blue and red respectively), indicates mean contrasts of 6.9 and 5.7 x10-10 respectively.

Speckle nulling demonstrations with the HCIT



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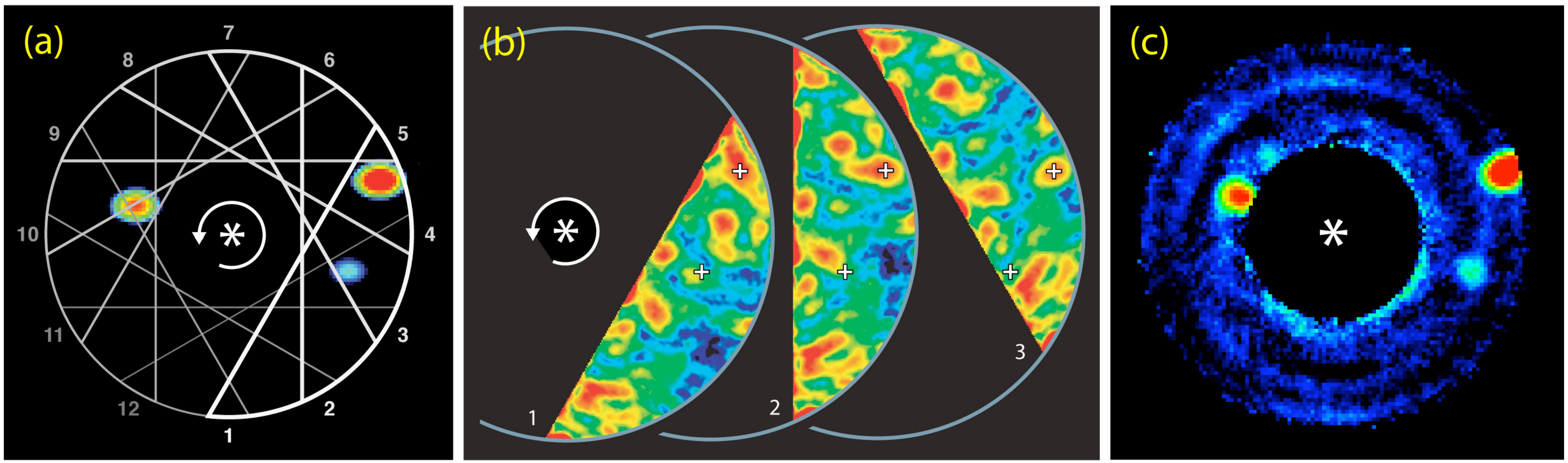
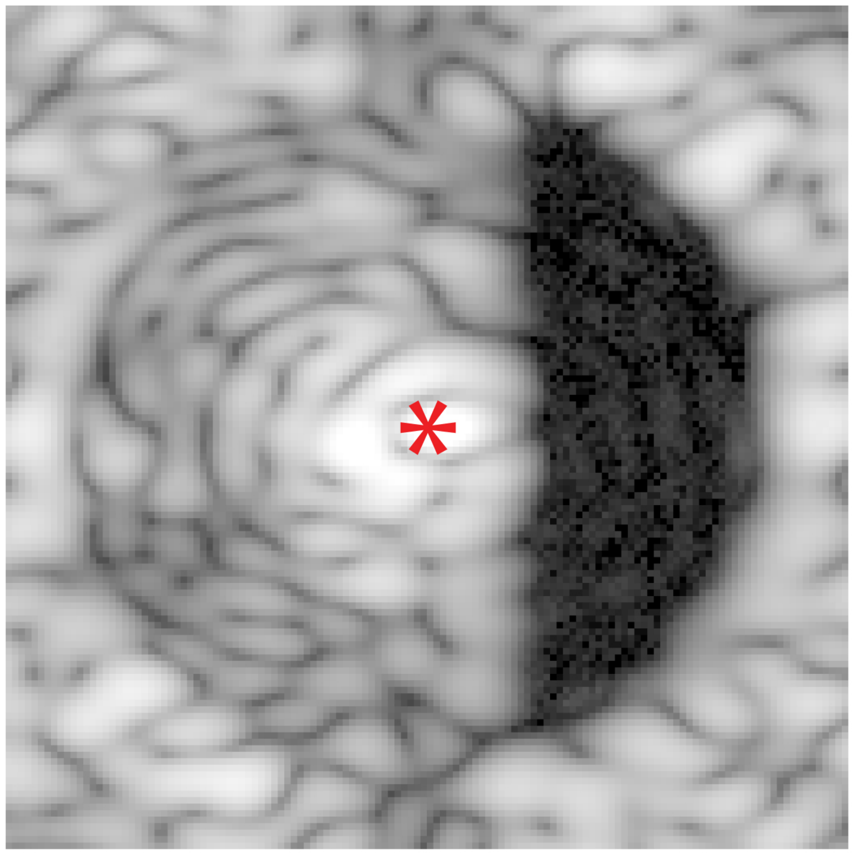
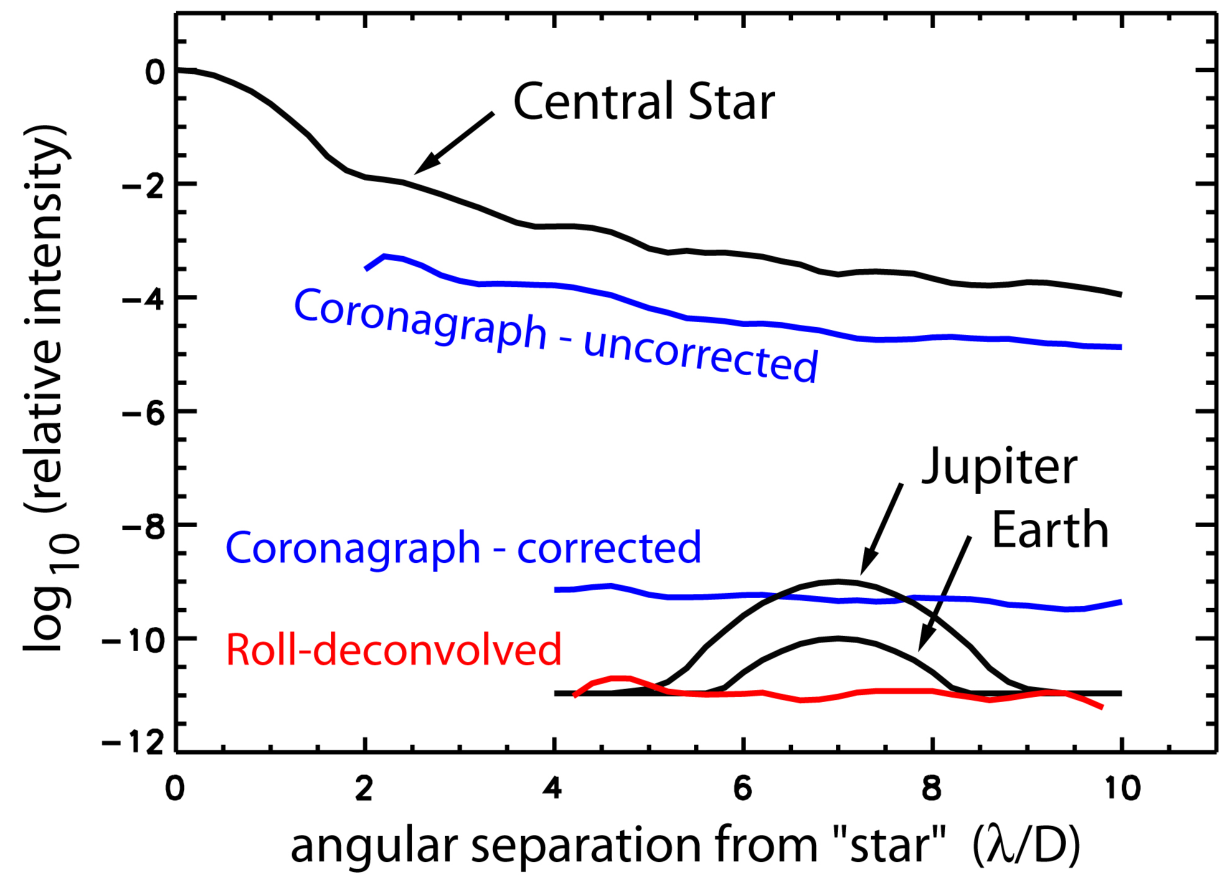
Roll deconvolution with HCIT data



Simulation of roll deconvolution with a sequence of 480 consecutive HCIT images taken open-loop over a period of five hours. (a) Three "planets" with the star PSF, but reduced to relative intensities of 10, 5, and 1x10-10. Rotation of the "telescope" and the D-shaped dark field is indicated by the wire grid. (b) Three of the rotated fields are shown, with the simulated planets superimposed (crosses). The 480 images were segregated into 48 sets of 10, and used to construct 48 fields rotated in 7.5 degree increments. (c) The result of roll deconvolution on the set of 48 images by John Krist. The nominal Earth (4 o'clock) and Jupiter (2 o'clock) are clearly seen.

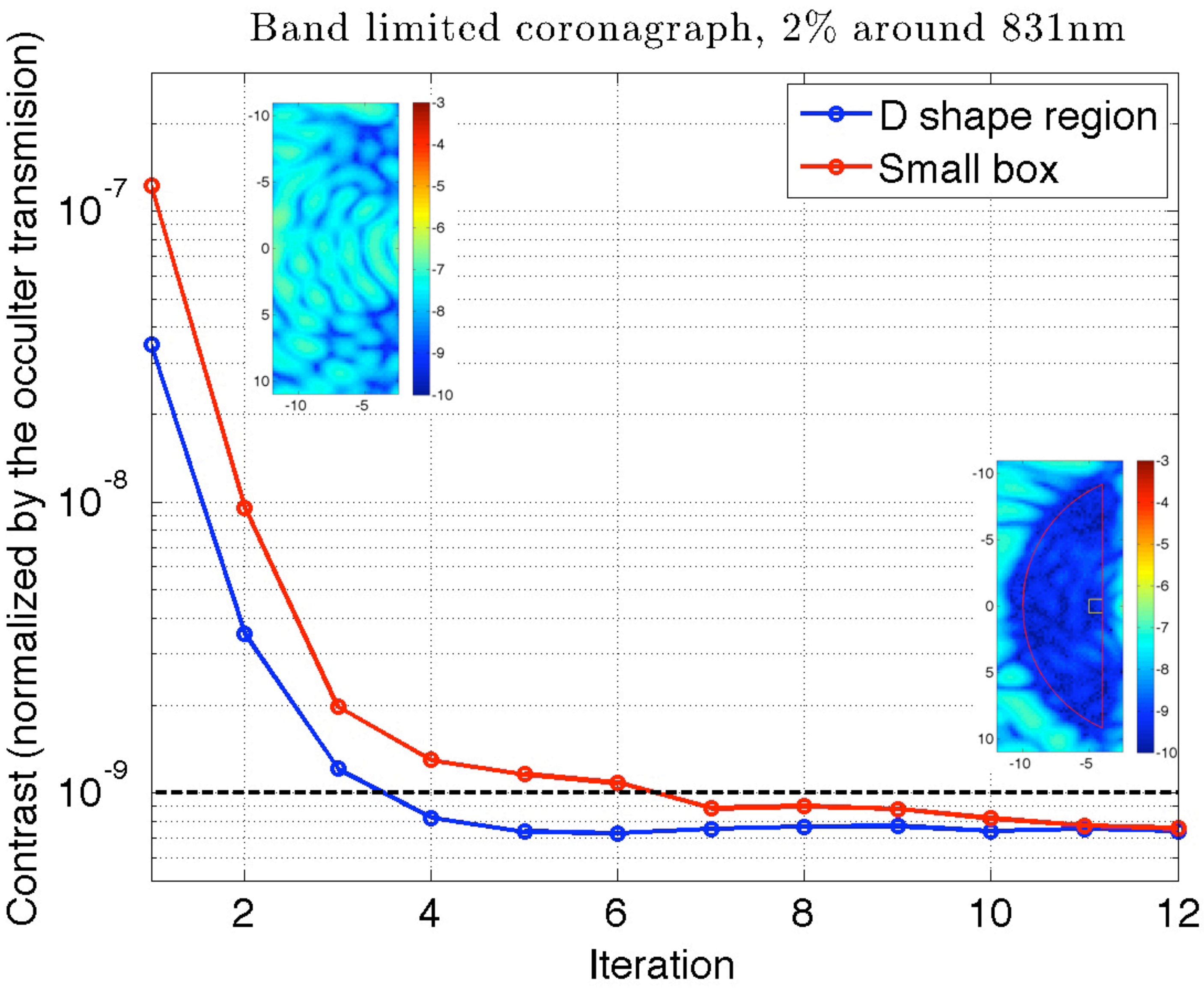
Coronagraph PSF comparison, including roll deconvolution





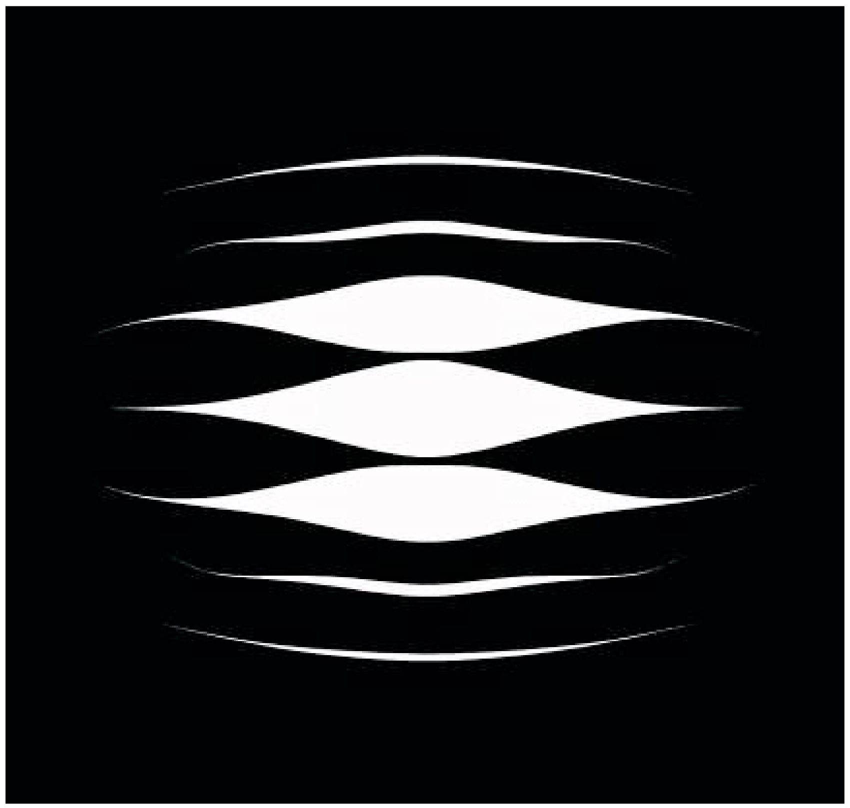
Comparison of azimuthally averaged PSFs of (a) the star, with focal plane mask offset and Lyot stop in place; (b) the coronagraph field with all DM actuators set to equal voltages; (c) the coronagraph with DM set for a dark half-field; and (d) the result of simulated roll deconvolution with the set of 480 consecutive coronagraph images.
PSFs of a nominal Earth and Jupiter are also indicated.

New wavefront correction algorithms



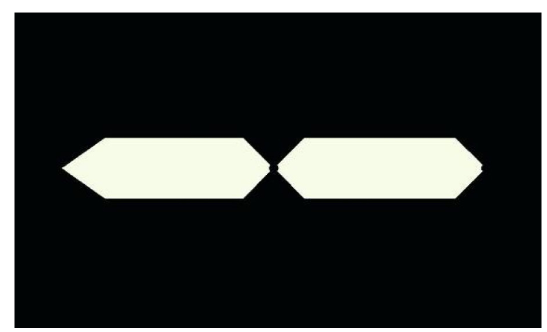
Improved convergence rates have been demonstrated recently on the HCIT with a new "electric field conjugation" algorithm (Give'on, 2007)

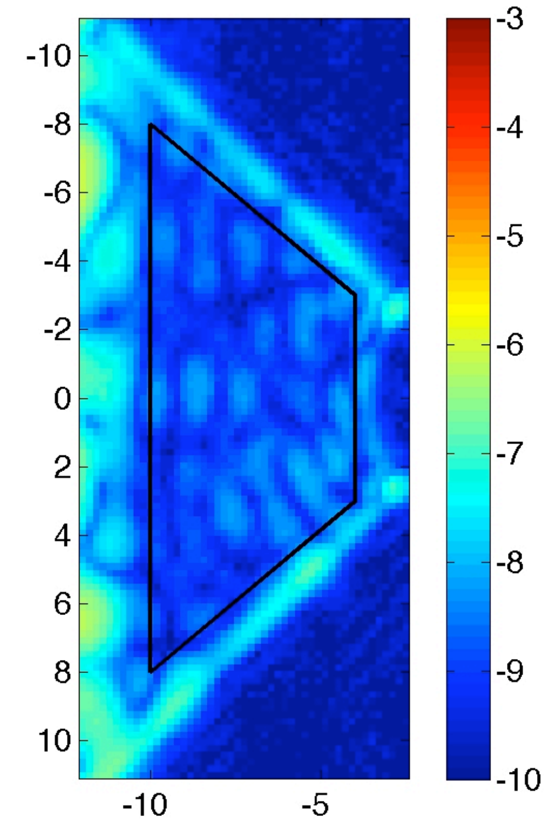
Shaped pupil coronagraph experiments on the HCIT



Shaped pupil mask

Focal plane mask

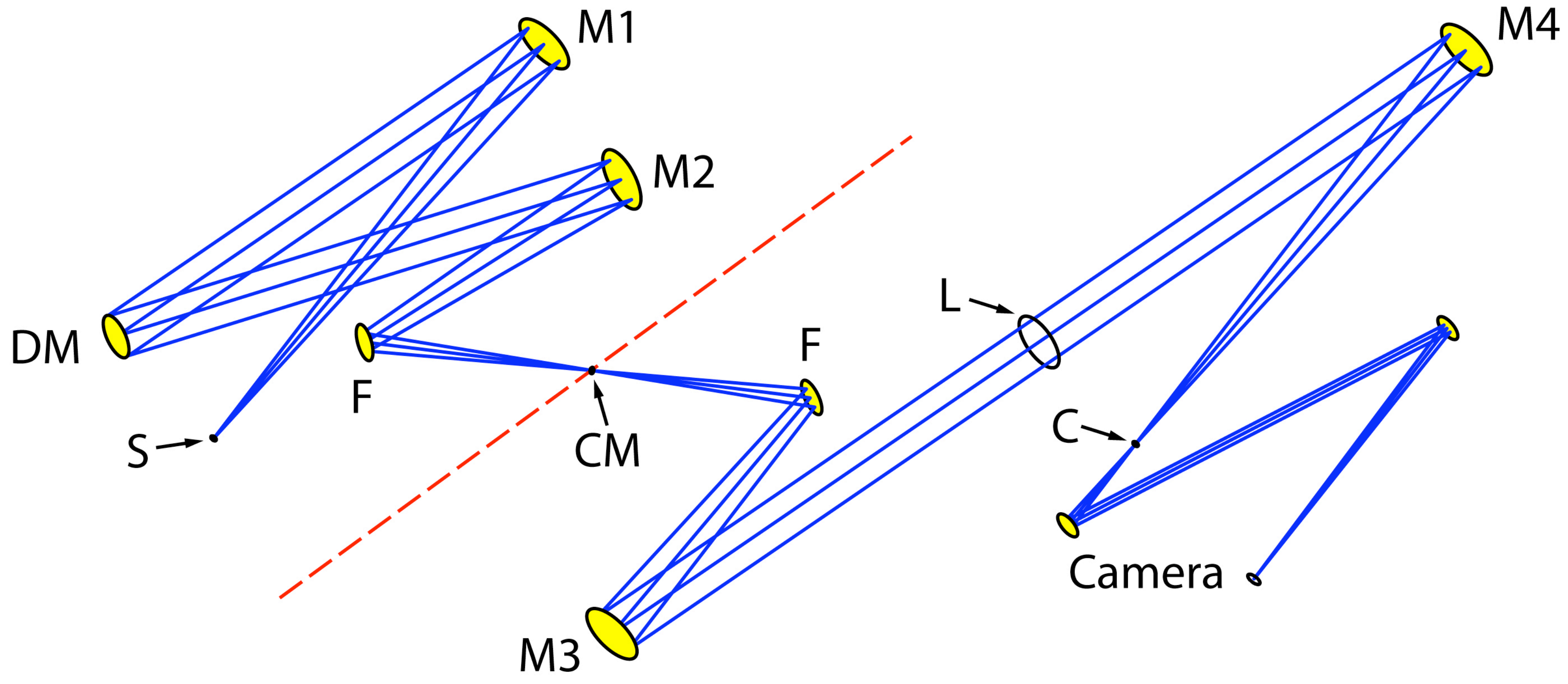




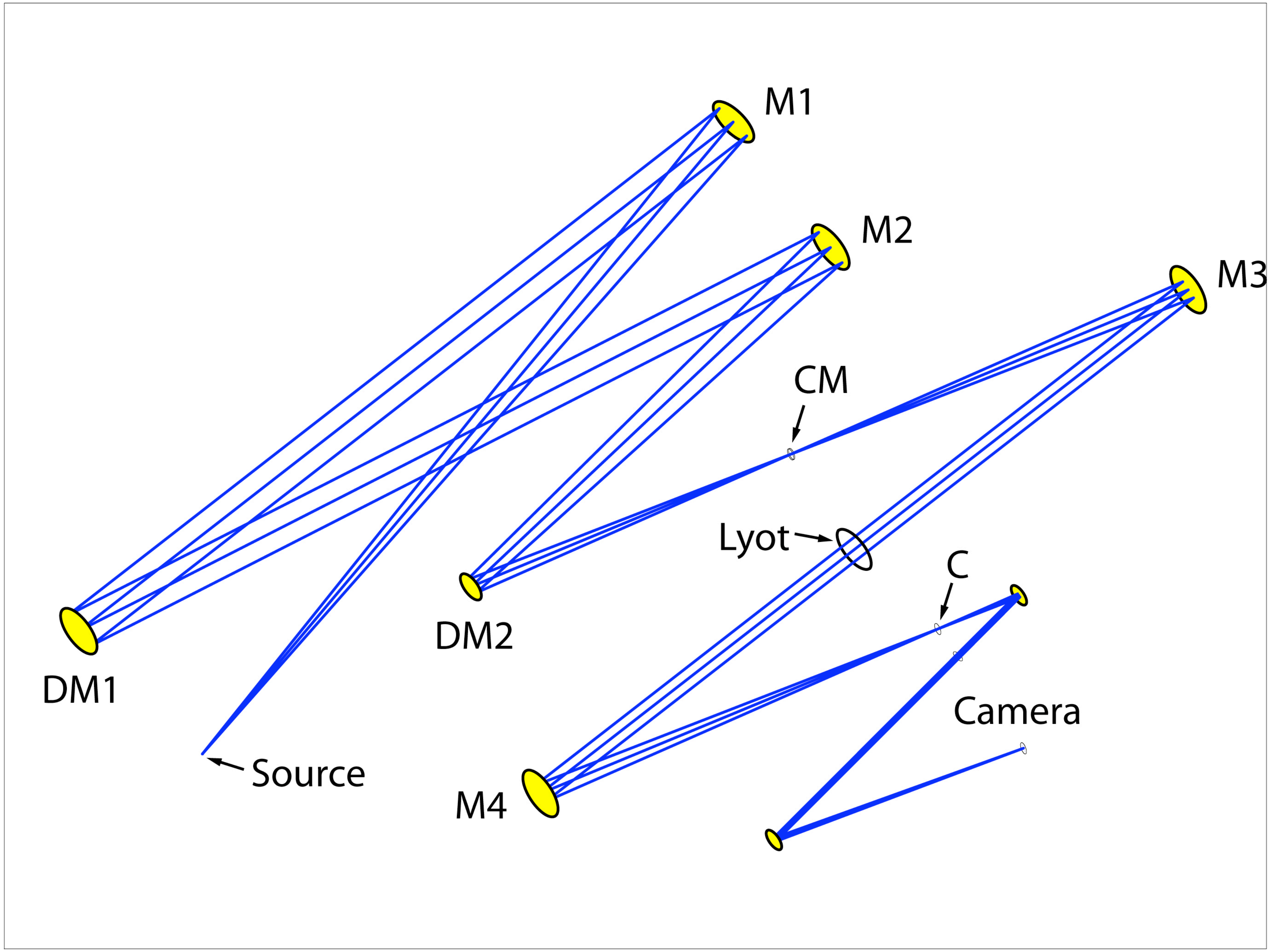
High contrast field

At left, the transmittance profile of a representative shaped pupil apodization (black indicates opaque, white indicates clear) currently mounted and selectable in the HCIT. At center, the corresponding “bowtie” image plane mask. This “Ripple 3” design (Belikov et al.) is one example of alternative coronagraph schemes under investigation with the HCIT. Achieved contrast to date is 3.5x10-9 in 2% bandwidth, and 6x10-9 in 10% bandwidth.

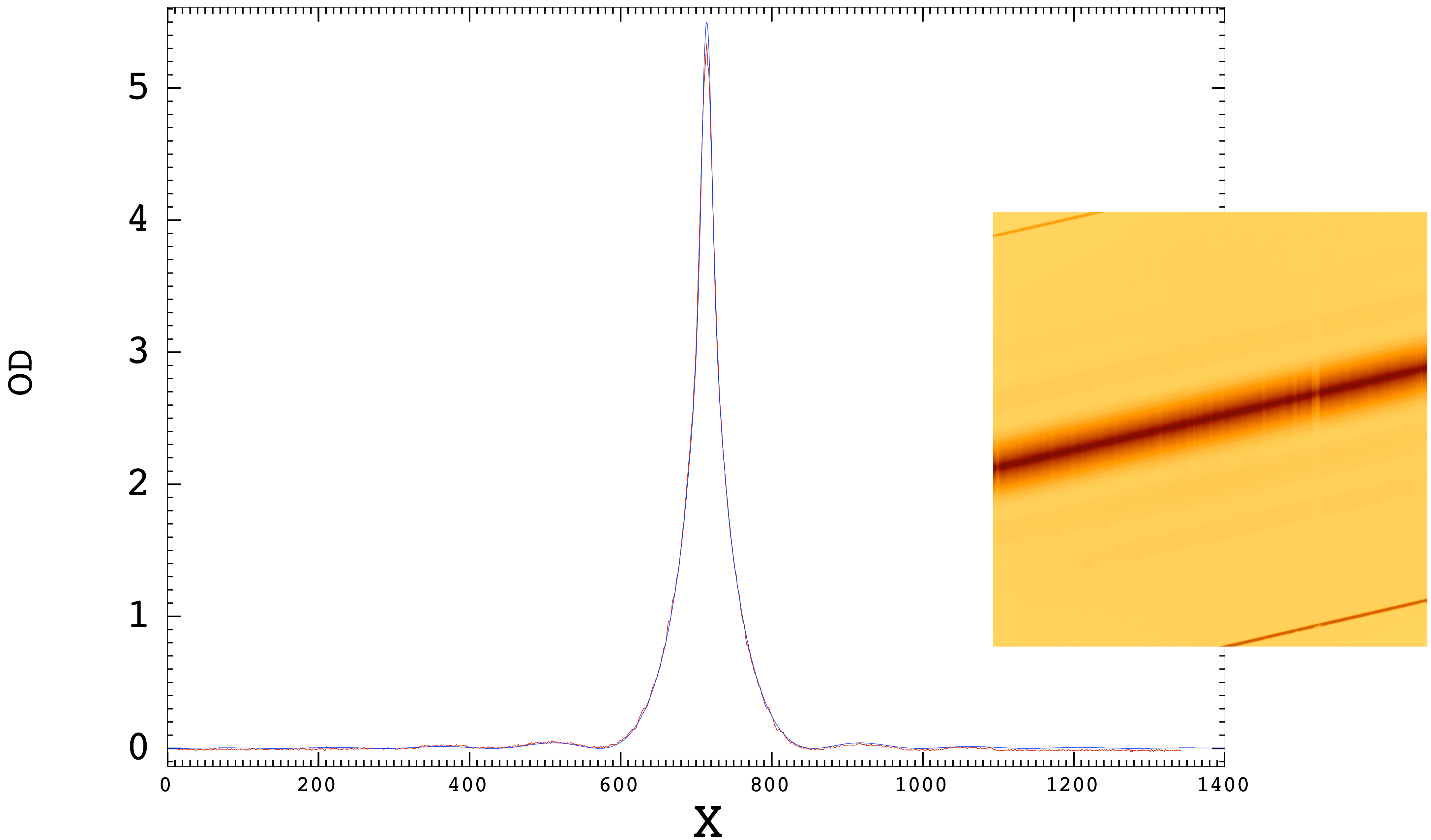
Current optical layout with a 32mm DM and SORL OAPs



Planned layout with 64mm DM, longer focal length OAPs, and optional 2nd DM

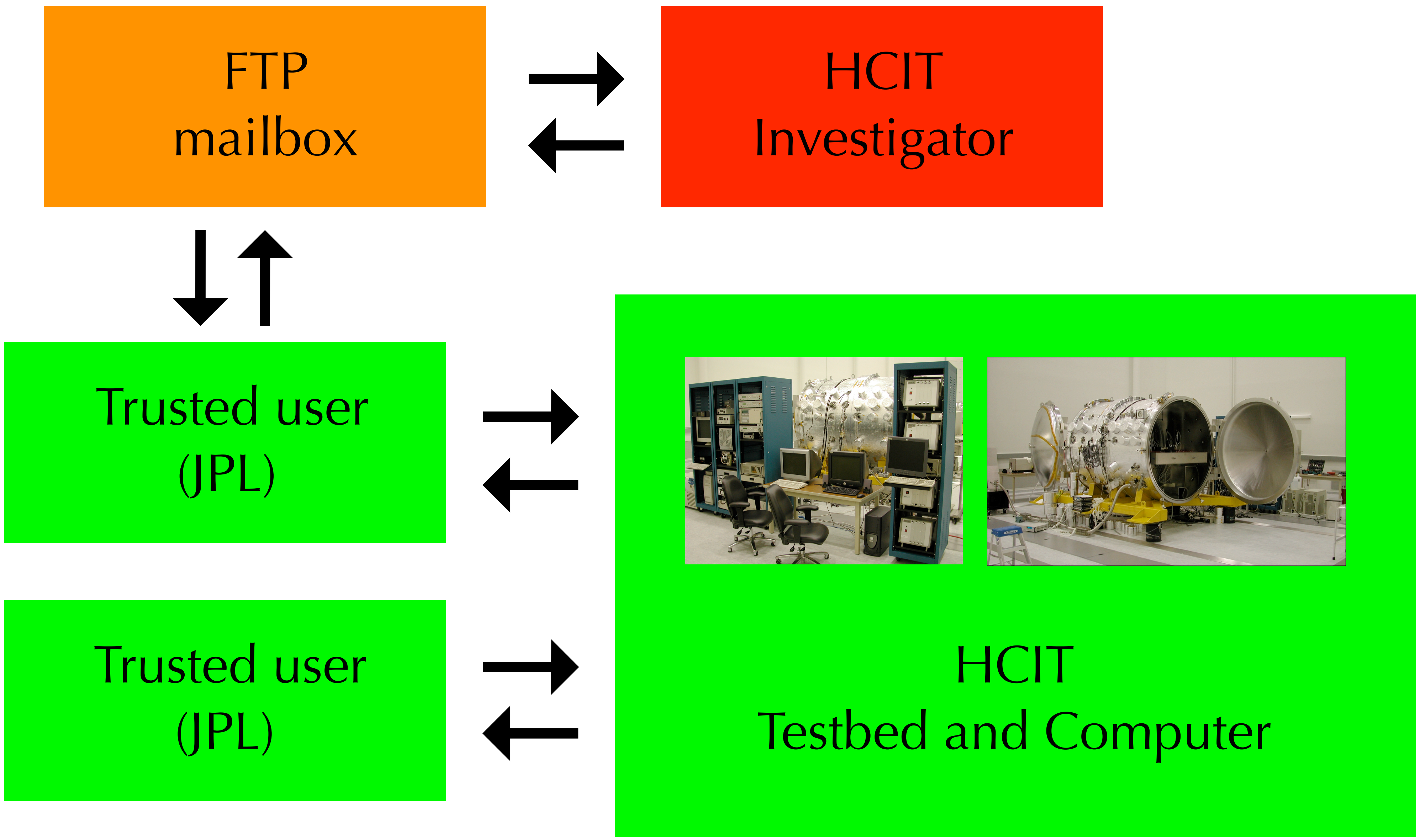


Functional check of new vacuum deposition system for metal/dielectric masks



Exposure on a CCD as a stand-in for vacuum deposition:
specified OD profile in blue, measured profile in red

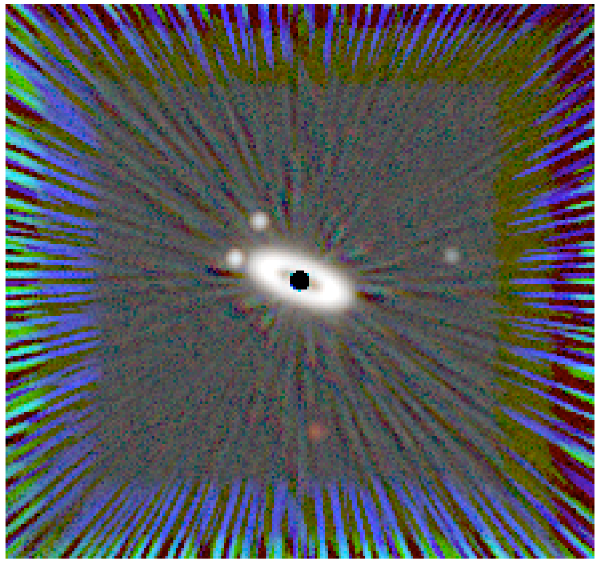
Investigations with the HCIT



HCIT Summary

- HCIT consistently provides a wavefront control contrast floor of 5x10-10
  - This implies surface figure control of 0.04 nanometers rms
  - New algorithm provides faster convergence (Give'on)
  - New (64mm) DM and improved driver system will push the wavefront control contrast floor below 1x10-10 this year
  - Dual-DM configuration will improve bandwidth and contrast in the coming year
- Lyot coronagraph using HEBS occulting masks provides 7x10-10 contrast in 2% bandwidth, 6x10-9 contrast in 10% bandwidth
  - Contrast performance matches computational models within 20%
  - New occulting materials (profiled metallic masks) promise contrast better than 10-9 in bandwidths of 10-20% later this year
  - Testbed stability enables reduction of the contrast floor to 10-11 using image subtraction
- Alternate coronagraph architectures are under investigation
  - Shaped pupil investigations (in progress this month, Belikov et al.)
  - Preparing for PIAA experiments in the coming year

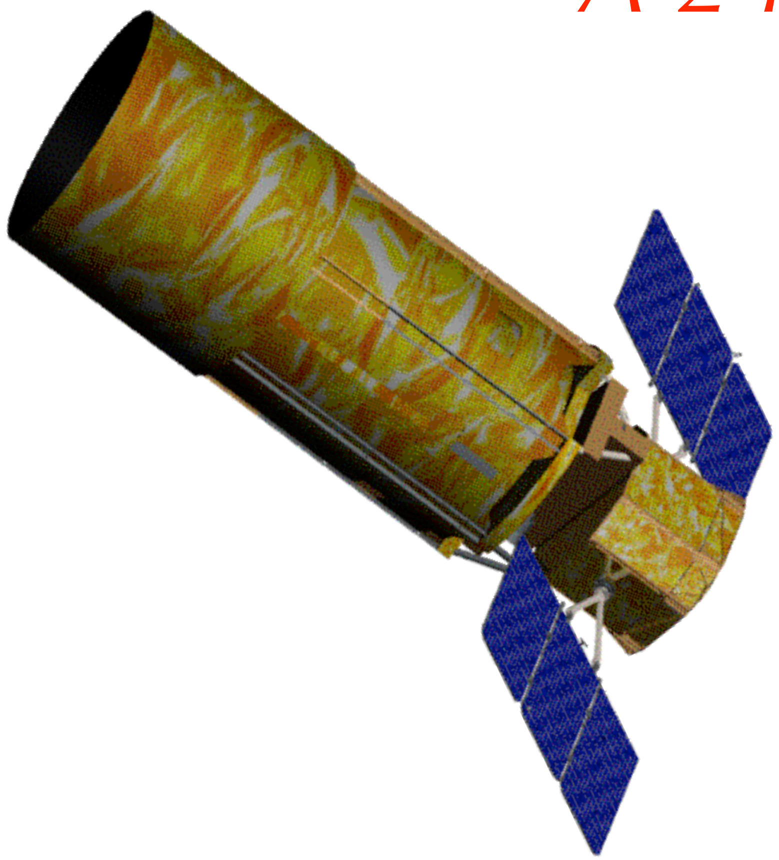
The exploration of nearby Planetary Systems

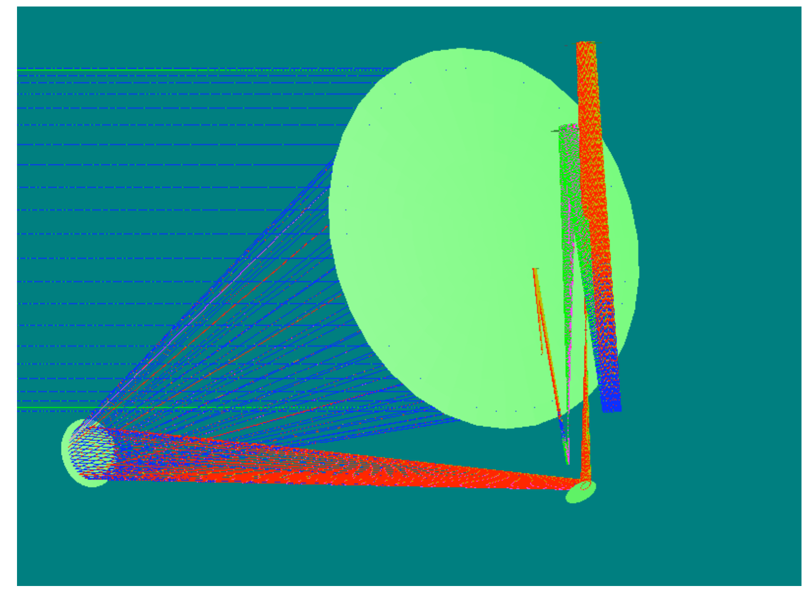


Simulated image: Altair (v=0.8 at 5.1pc)
Exposures in V, R, and I bands
Jupiters at 5, 10, and 20 AU,
Brown dwarf at 40 AU, and 5-zodi disk

- Emphasis on the characterization of extra-solar planetary *SYSTEMS*
- Major planets and dust/debris disks provide the context for exosolar systems that may contain Earth-like planets
- Actively-corrected coronagraphic telescope enables direct imaging and spectroscopy of companions orbiting the nearby stars
- Design and analysis of the proposed Eclipse mission can be extended to a medium class ($600M) mission with a 2-m class coronagraphic telescope

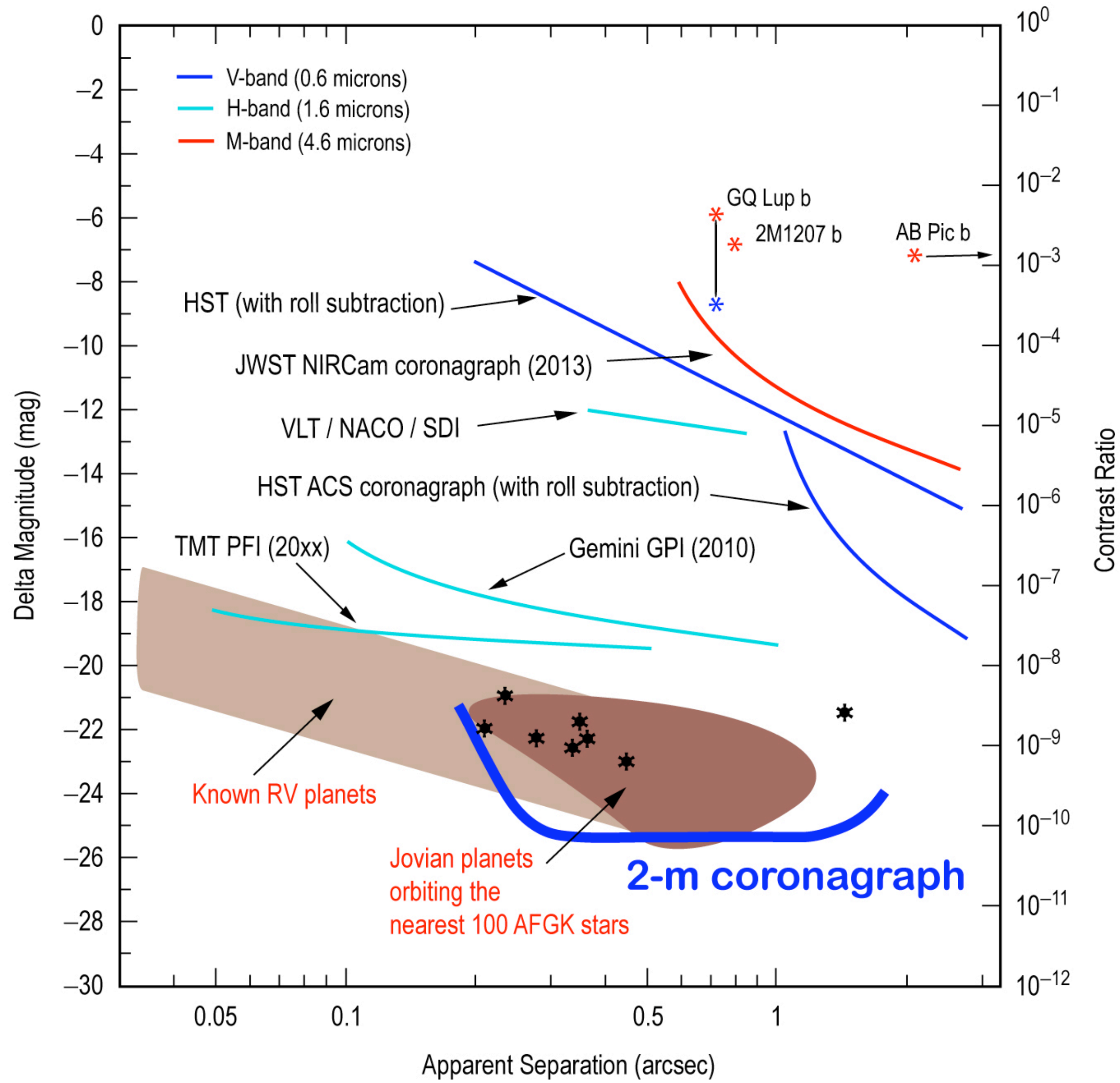
A 2-meter Mission Concept





- Unobscured off-axis telescope with 2-m class primary mirror
- Active wavefront sensing and correction, all sensing at the science focal plane
- High contrast coronagraphic camera, selected from an evolving list of coronagraph architectures (Lyot, PIAA, shaped pupil, and possibly others)
- Structural and thermal design for stable and precise optical alignment
- Emphasis on simplicity of design and minimum of optical elements
- Spacecraft in L2 halo orbit for a 3+ year mission

Discovery space for a 2-meter Mission Concept



Exoplanet discovery space for a 2-m class coronagraphic telescope, and comparisons with existing and proposed missions and techniques. Known RV planets within reach of the 2-m coronagraph are indicated by the (black) asterisks.

Access to Nearby Planetary Systems

- Imaging and spectroscopy of known radial velocity planets
  - Nine nearby stars host RV planets with apastron distances > 0.25 arcsec
  - Existing ephemerides provide timing for maximum visibility
  - Measure colors, take spectra, resolve sin(i) ambiguity in mass
- Discovery of new giant planet companions
  - RV surveys are incomplete for orbital periods > 8 years, early F and hotter stars lacking strong metallic lines, stars with high chromospheric activity, and face-on systems
  - Potential to discover mature 5-10 AU Jovian planets orbiting as many as 200 nearby stars
  - Among these, 30 stars within 25 pc harbor close-in RV planets
- Debris disks and exozodiacal dust
  - 1000 times more sensitive than HST, to reach as faint as Kuiper Belt analogs
  - Direct evidence of ongoing collisions between unseen small bodies
  - Unseen planets impress dynamical signatures in the debris structures, including rings, gaps, warps, and asymmetries
- Terrestrial planets
  - Potential to detect Earth-sized planets orbiting a 5-10 nearby stars

End